ADOM (Air Deployed Oceanographic Mooring)

ADM (Advanced Development Model) Thermal Ice Drill

Test Results

Tests Conducted at

The Cold Regions Research and Engineering Laboratory

Hanover, New Hampshire

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University of New Hampshire

September, 1982

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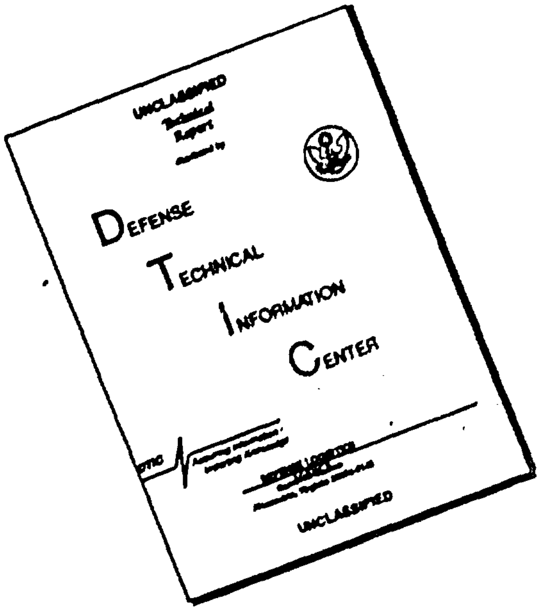

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A series of tests of the "Advanced Development Model" (ADM) thermal ice drill were conducted at the U.S. Army Cold Regions Research and Engineering Laboratory during August 1982, as part of the Arctic ADOM (Air Deployed Oceanographic Mooring) project. The drill is part of an autonomous system intended to facilitate the collection of data in inaccessible regions of the Arctic. This report describes the drilling concept, test procedures, results, and conclusions.

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TABLE OF CONTENTS

ADOM (Air Deployed Oceanographic Mooring)

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Tests conducted at the Cold Regions Research & Engineering Lab

Hanover, New Hampshire

I. Introduction

A series of tests of the ADM Thermal Ice Drill were conducted at the U.S. Army Cold Regions Research and Engineering Lab during August, 1982 to verify previous work done on the CVM (Concept Validation Model) Ice Drill, and prove system reliability of drill mechanism under autonomous computer control.

The ADM Drill was found to be a very reliable and efficient means for ice cover penetration. The mechanism worked very well with no major malfunctions in sensor or control systems. All ice penetrations were under complete computer control, with automatic cable payout and tensioning allowing a simulation of its intended service.

II. The Drill Concept

The ADM recirculating water jet drill utilizees a jet stream of water which is pumped by a three-stage centrifugal pump through a heating chamber and jetted out a nozzle at the drill tip. The highly turbulent action of the warmed stream produces a high heat transfer coefficient and efficient transfer of heat to the ice.

Before the recirculating water jet can be used the drill must submerge itself in its own melted water, thus priming the centrifugal pump. This is accomplished by the use of a parabolic

shaped hot point which initiates the drilling process. The drill melts into the ice until water reaches two sensors located four inches above the pump intake. When these sensors are triggered the power is diverted from the hot point to the water heating chamber and the pump. (See Figure 1)

The hot point is heated by nine cartridge heaters arranged in banks of three and controlled through three thermisters equally spaced within.

The water heating chamber contains 20 heaters arranged radially within a tube and is divided into four banks for control. Two of every five heaters within a bank are equiped with thermisters fixed to monitor the surface temperature of the heater for control purposes.

A modified commercial three stage centrifugal pump, driven by a 1 1/2 hp submersible motor,recirculates the water through the chamber and out a 5/8" nozzle at the tip of the hot point.

The drill is controlled by a 6100 micorprocessor located in a water tight chamber at the top of the drill. The control program is designed to adapt to system failures and environmental hazards to attempt completion of assigned mission through alternate strategies. The program is capable of evaluating sensor feedback reliability and making control decisions based upon it. Erroneous thermister data can be masked out and control given to reliable input still available. Sudden loss of meltwater through the encountering of voids and cracks in the ice can be sensed and the drill can be reinitialized to provide meltwater. The computer also has the ability to recognize a

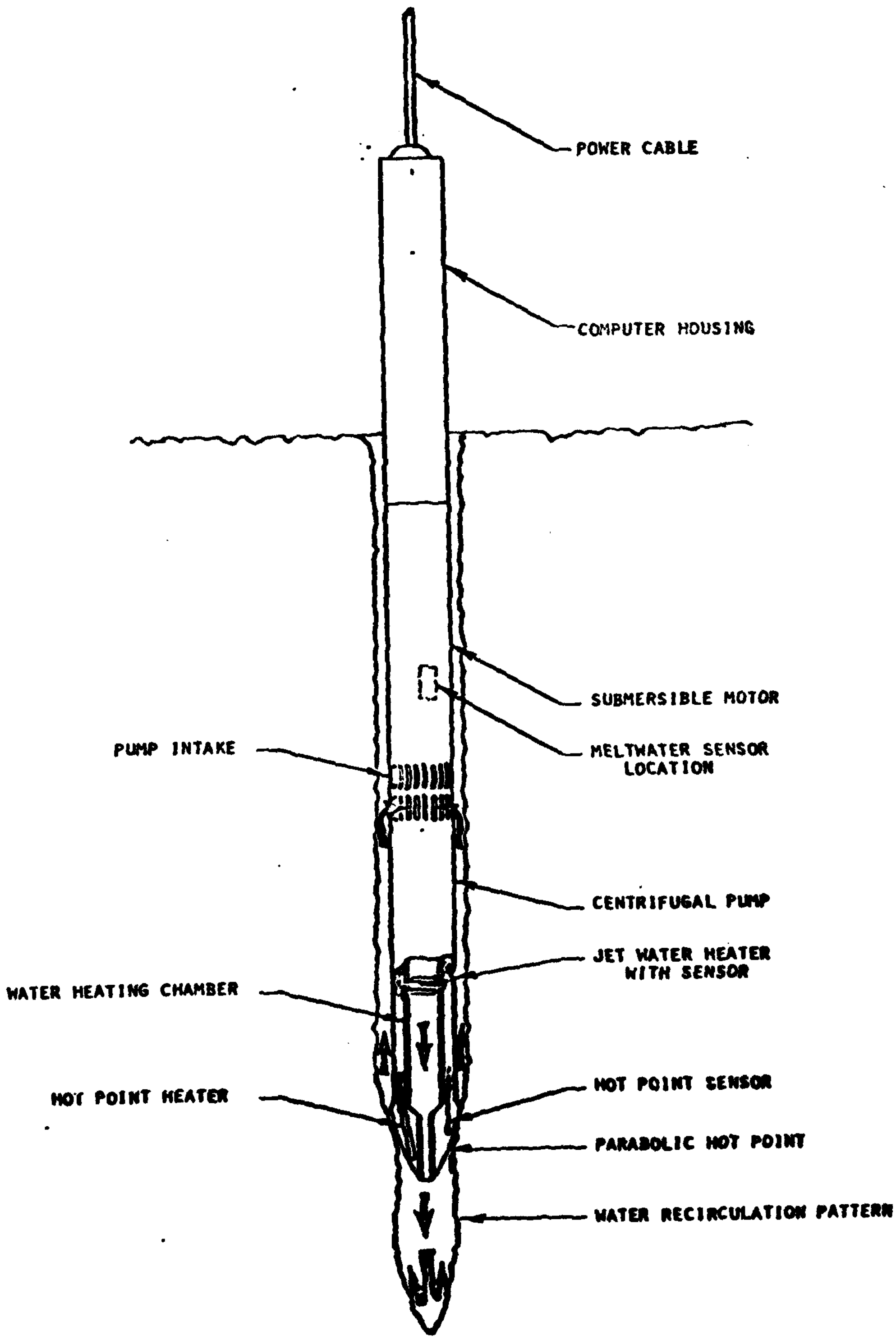


FIG. 1 ADVANCED DESIGN MODEL ICE DRILL

program failure; and restart and if that fails, go to a hardware control scheme.

Guidance of the drill depends on cable tension coupled with low center of gravity and high center of buoyancy to keep the drill vertical.

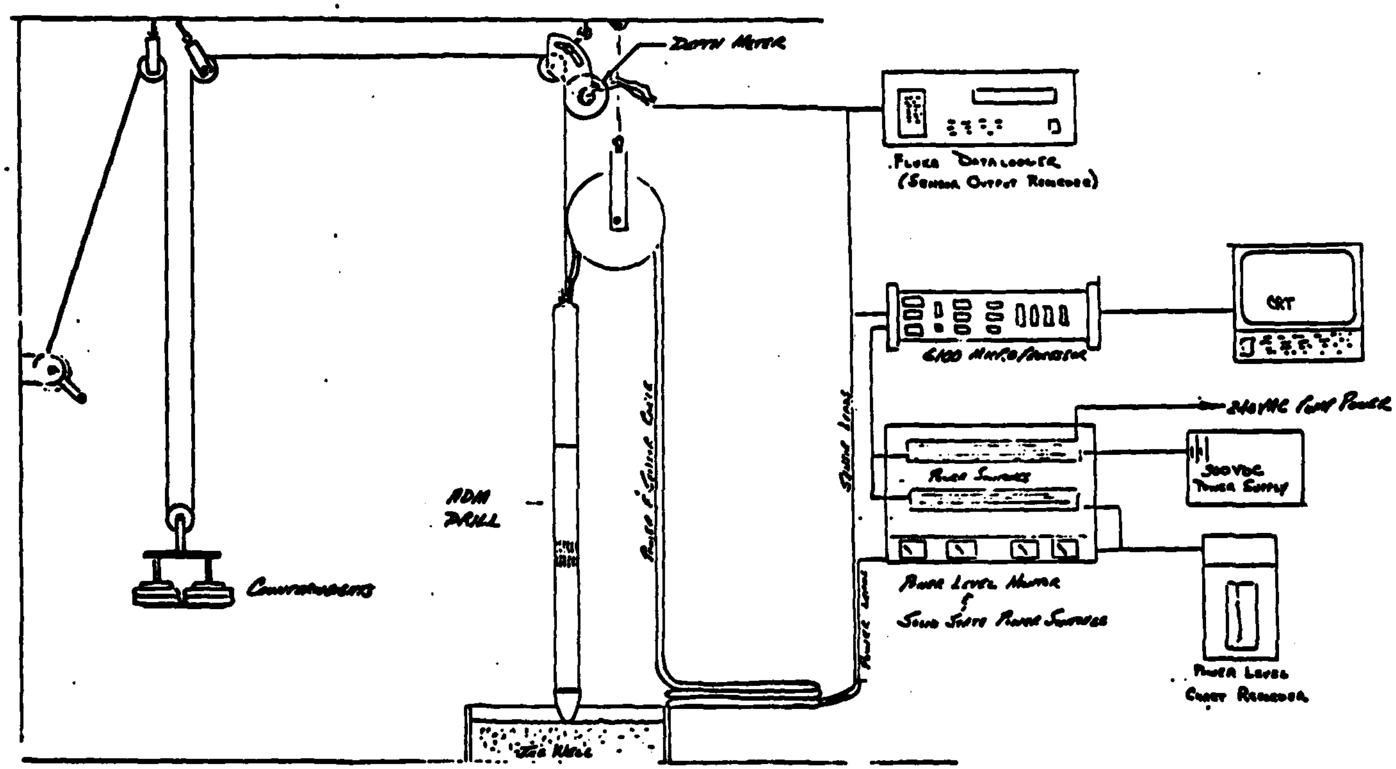
III. Test Setup and Apparatus

Tests were conducted at the U.S. Army Cold Regions Research and Engineering Lab deep well facility. The ice well is three feet in diameter by 200 feet deep and is maintained at -25^{o} C. Thermocouple probes in the ice provided temperature readouts. The drill was hung by a steel cable which ran back over a system of low-friction pullies which held a counterweight to provide uniform tension for guidance (see Figure 2). The end of the cable was fixed to a winch to allow more cable to be paid out and the drill to be recovered.

The drill was powered by a lead-acid battery pack consisting of 50 12V deep charge batteries linked in a series/parallel combination resulting in a nominal 300VDC. The drill pump motor was supplied with 240VAC which was available at the test facility.

For the tests the drill control microprocessor and power switches were kept external to allow for monitoring of sensor feedback and the changing of operating parameters.

Power levels of both the drill heaters and pump drive were manually recorded from meters as the drill ran. A chart recorder made a record of the duration and level of power to the drill heaters. A multichannel fluke data logger chart recorder



ADM TEST APPARATUS

Figure 2

monitored all drill sensors, ice temperature, and readings from the depth meter. Readings were printed once every minute along with the time.

The depth meter consisted of a 10 turn potentiometer linked by pully to the suspension cable. Both the source voltage and the slider voltage were recorded which could be translated to travel distance of the drill.

Hole sizes were estimated on the first few tests by physical measurement of the hole in its first few feet. Subsequent holes were sized by pumping a known quantity of melted water from the hole and measuring the change in height of the water level. An average size could then be accurately calculated.

IV. <u>Test Procedure</u>

The test procedure was simple as the drilling required no physical assistance or intervention once initiated. The drill was lowered to the ice, counter weights set and the computer test operating system program given its start command. The drill was then allowed to control itself until manually terminated at the end of each run. The hole was then pumped out, and measurements taken.

V. <u>Results</u>

Figures 3 and 4 summarize the data and pertinent calculations of power, efficiency, and rates of both drilling modes. Figure 5 summarizes drill performance during test #3.

The ADM drill typically produced a hole with an average diameter of 6.5 inches. In its initialization phase, where it utilizes a 5.8 kW parabolic shaped hot point, the drill proceeded

Figure 3

ADOM ADVANCED DEVELOPMENT MODEL (ADM) THERMAL ICE DRILL TEST RESULTS

Conducted at Cold Regions Research & Engineering Lab

Hanover, NH

July 26, 1982 - August 24, 1982

HOT POINT

Test #	Date	Drill Weight	Sample Interval Min	Run Time Min	Δ Z Depth in	Average Power kW	Total Power kWh	Ice Temp.	Drill Rate in/Min	Temp. Band	Overall Efficiency
1	7/26	41.5#	t = 0 to t = 27	27	30.5	4.29	1.93	-25^oC	1.13 (2.87cm)	high - 105^oC low - 96.5^oC	58.4%
2	7/29	41.5#	t = 0 to t = 24	24	33.7	5.50	2.20		1.40 (3.56cm)	high - 115^oC low -110^oC	53.0%
3	8/2	61.2#	t = 0 to t = 21	21	30.6	5.91	2.07		1.46 (3.7cm)	high - 115^oC low - 110^oC	53.5%
4	8/5	61.2#	t = 0 to t = 31	31	37.0	5.25	2.71		1.19 (3.03cm)	high - 115^oC low - 110^oC	50.5%
5	8/11	61.2#	t = 0 to t = 28	28	39.0	5.81	2.71		1.42 (3.6cm)	high - 115^oC low - 110^oC	50.9%
6	8/13	41.5#	t = 0 to t = 26	26	38.5	6.74	2.92		1.48 (3.76cm)	high - 115^oC low - 110^oC	48.9%
7	8/19	51.5#	t = 0 to t = 24	24	34.4	5.73	2.29		1.43 (3.64cm)	high - 115^oC low - 110^oC	55.2%
8	8/24	51.5#	t = 0 to t = 22	22	29.0	4.61	1.69	-25^oC	1.38 (3.51cm)	high - 115^oC low - 110^oC	61.7%

Figure 4

ADOM ADVANCED DEVELOPMENT MODEL (ADM) THERMAL ICE DRILL TEST RESULTS

Conducted at Cold Regions Research & Engineering Lab

Hanover, New Hampshire

July 26, 1982 - August 24, 1982

WATER JET DRILLING

Test #	Date	# W.H. Banks On	# H.P. Banks On	Drill Net Weight	Sample Interval (Min)	Run Time (Min)	Z Depth (in)	Ave. Power (kW)	Total Power (kWh)	Ave. Hole Size (in)	Ice Temp. °C	Drill Rate in/Min	Overall Efficiency	Max. Drill Depth	
1	7/26/82	4	0	0	37 to 42	5	13.5	12.3	1.02	6.5 approx.	-25°C	2.7 (6.86cm)	71%	48"	(1)
2	7/29/82	4	0	approx. 15# as it submerged	t = 25 to t = 31	5	14.6	12.26	.77	6.5		2.43 (6.17cm)	53.5%	84"	(2)
				10.2#	t = 36 to t = 53	18	42.8	11.99	2.292			2.52 (6.39cm)	54.1%		(3)
				10.2#	t = 61 to t = 78	17	46.9	11.6	3.28			2.76 (7.01cm)	62.7%		
3	8/2/82	4	0	20.2#	t = 28 to t = 71	43	126.3	12.02	10.39	6.5		2.88 (7.3cm)	70.3%	201"	
4	8/5/82	3	2	20.2#	t = 34 to t = 121	87	257	12.61	18.29	5.75 approx		2.95 (7.5cm)	48.9%	333"	(4)
5	8/11/82	4	0	20.2#	t = 28 to t = 92	60	196.8	13.3	14.08	6.67 measured average		3.095 (7.86cm)	69.1%	246"	
6	8/13/82	4	1	10.2#	t = 21 to t = 56.3	35.3	110	13.85	8.13	6.96 measured average		3.1 (7.89cm)	69.8%	210"	
7	8/19/82	4	1	10.2#	t = 27 to t = 42	15	50.3	13.46	3.37	6.94 measured average		3.35 (8.52cm)	76.5%	204"	
					t = 47 to t = 75	28	85.8	13.15	6.14			3.06 (7.78cm)	71.3%		
8	8/24/82	2	3	10.2#	t = 31 to t = 85	54	157	11.88	10.69	6.21 measured average		2.91 (7.39cm)	58.8%	300"	

(1) Water jet phase ended after 5 minutes (pump coupling broke)
(2) At t = 33 added 10.2# to drill weight
(3) Cable hung up on pully at t = 53
(4) Erratic hole shape. Drill got stuck pulling it out at transition point of H.P. to water jet (37" down)

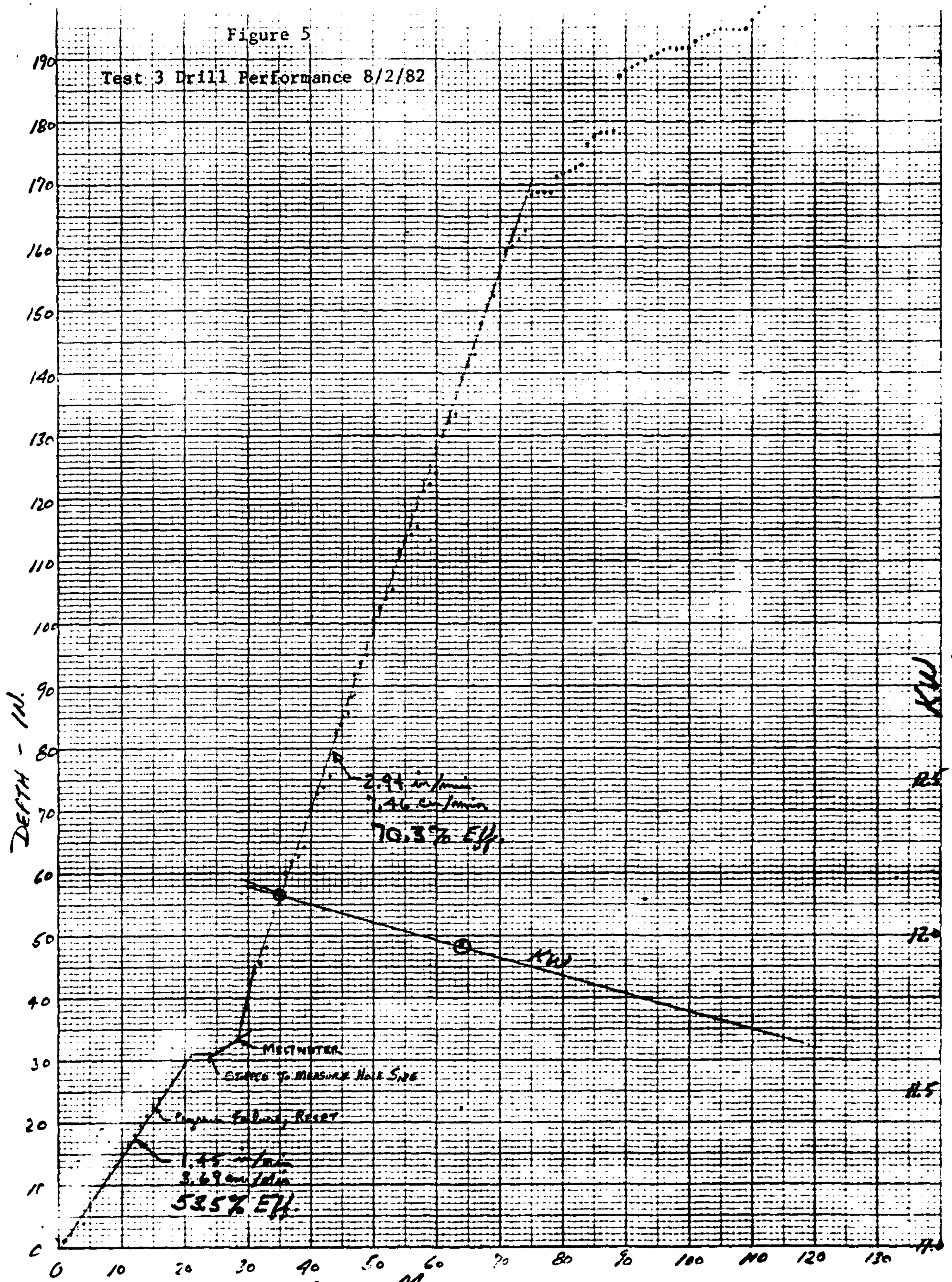


Figure 5
Test 3 Drill Performance 8/2/82
DEPTH - IN.
TIME - MIN
KW
2.94 in/min
7.46 cm/min
70.3% Eff.
1.45 in/min
3.69 cm/min
53.5% Eff.
Program Failure, Reset

at an average rate of 1.4 inches/min. (3.5 cm/min.) to a depth of 33 inches (83.8 cm) at an overall efficiency of 55%. At that point sensors detected that the drill was submerged sufficiently for the internal centrifugal pump to be activated and the transition to the water jet phase of drilling was initiated.

The water jet ran at a steady state power level of about 12.5 kW and an overall efficiency of 70% taking into account an additional 2.3 kW provided to the pump drive motor. The drill in this phase proceeded at an average rate of 2.9 inches/min. (7.4 cm/min.).

The drill path was irregular and typically drilled at a 4.5° angle to perpendicular. This angled drilling is recognized as a potential problem. Physical limitations of the ice well diameter prevented the continuation of the drilling process to prove or disprove that the drill could continue at that angle or whether the angle would increase enough to cause a penetration problem. Continuation of a 5° angle for penetations in the order of 15 meters could be acceptable.

Attempts were made at correcting this problem. Proposed reasons for the non-perpendicular drilling are:

1. Drill cable was bulky due to an unpackaged computer - all sensor and power leads had to be run to the surface. This cable could have put an uneven tension on the drill causing or at least contributing to the problem.
2. Drilling is an erratic process where the probe melts in slowly while the ice is eroded away ahead of it. Then the drill will drop by 5-6 inches and resume its slower rate. This erratic dropping sometimes caused the drill

to cock slightly, which caused the water jet to erode ice at an angle. The drill could then drop into the angled hole, perpetuating an angled hole.

3. The water jet has a measured reaction force of 12# on the drill. When in operation dynamics of the recirculation around the drill head can cause a rocking motion on the drill causing an erratic drilling.

One method used to correct this angled hole was to divert power from water jet heaters to the hot point to try to rid the slow melt and then 5-6 inch drop action of drilling. We tried running three water heater banks with two hot point banks and two water heater banks with three hot point banks. In both cases the drill went to the maximum cable length available (27 feet). Consequences of this were a reduction of efficiency to 58% in the jet mode. The hole was egged in areas and erratic at the point where the drill transitioned from the hot point to the water jet. This caused the drill to get stuck when pulling it back up. . The hole at the transition was about 4 3/4 inches x 6 inches. Beyond this point the average diameter was 6.2 inches, but there were erractic sections which gave an effective diameter of 5 3/4 inches.

Control of the hot point by computer worked very well. Temperature parameters were maintained and consistant results were obtained.

Although the water jet control program was active during tests, it was found that drilling in this mode is essentially a steady-state operation, with surface temperatures on the heaters

holding steady at about 6 $^{\circ}$C. This steady-state condition meant that heaters never cycled off/on. However, the control program was tested and performed correctly, assuring that, had sensors malfunctioned, the program would be effective.

VI. Conclusions

The testing of the ADM could and should be termed successful. Power requirements of previous CVM tests were confirmed. Optimum control parameters were defined for this model and drilling under complete autonomous computer control proven reliable. Overall the mechanism performed well, with only minor malfunctions, which were quickly identifiable and corrected. Testing indicates that the ADM would be an effective means for efficiently penetrating ice cover.

We cannot truly say we have a problem with steering. The mission objective is to plant sensors beneath 15 meters of ice. A 5° tilted hole could be acceptable although it is not ideal for a limited power supply. What has not been proven is that the drill could keep going at a 5° angle. The tank wall limited us to 17 feet at that angle. The drill might be increasing its angle as it goes. On the other hand, extended drilling may well allow the pendulum effect of the system to correct its path.

Packaging of the computer could present added control of the steering as we would have a compact uniform cable concentric with its suspension member, providing or assuring tension transmitted through the drill axis.

The success of this phase of testing would indicate the following steps in the drill development:

1. Packaging of the computer into its housing atop the drill.
2. A short series of verification tests of:
    a. Drill guidance
    b. Operation of drill with packaged computer with PROM software control.

APPENDIX I

Drilling Efficiency - Sample Calculations

1. The energy required to raise $1000 cm^3$ of ice from $-25^\circ C$ to $0^\circ C$

$$E = \rho V \ Cp \Delta T$$

Where ρ = Density of ice = $.9\ g/cm^3$

V = Volume of ice = $10^3\ cm^3$

Cp = Specific heat of ice = $.5\ cal/g - {}^\circ C$

ΔT = Temperature rise = $25^\circ C$

$$E = (.9)(10^3)(.5)(25)$$

$$E = 1.125 \times 10^4\ cal/1000cm^3$$

2. The energy required to melt $1000cm^3$ of ice

$$E = \rho VL$$

Where L = Latent heat of fusion = 80.2 cal/g

$$E = (.9)(10^3)(80.2)$$

$$E = 7.218 \times 10^4\ cal$$

Total Energy Required

$$E_T = 1.125 \times 10^4 + 7.218 \times 10^4$$

$$E_T = 8.343 \times 10^4\ cal$$

Converting to kWh

$$ET = (8.343 \times 10^4\ cal)\left(\frac{1\ mw - sec}{2.389 \times 10^{-4}\ cal}\right)\left(\frac{1\ kW}{1 \times 10^6\ mw}\right)\left(\frac{1\ hr}{3.6 \times 10^3\ sec}\right)$$

$$ET = \left(\frac{.097\ kW\text{-}hr}{1000cm^3}\right)\left(\frac{1000cm^3}{61.024in^3}\right)$$

$$ET = 1.5895 \times 10^{-3} \frac{\text{kWh}}{\text{in}^3}$$

On Test 3 during the water jet phase a volume of 4559.7in^3 of ice was melted.

Theoretical energy to raise the temperature from -25°C to 0°C and to melt the ice is

$$E_T = \left(1.5895 \times 10^{-3} \frac{\text{kWh}}{\text{in}^3}\right)\left(4559.7 \text{in}^3\right)$$

$$E_T = 7.248 \text{ kWh}$$

The energy applied to the drill was 12.02 kW for 43 min.

$$E_A = (12.02 \text{ kW})\left(\frac{43}{60} \text{hr}\right)$$

$$E_A = 8.614 \text{ kWh}$$

The energy applied to the pump motor was based on the use of an inverter at 90% efficiency

$$E_A = \frac{210\text{VAC } (10.1\text{A}) \left(\frac{43}{60} \text{hr}\right)}{.9}$$

$$E_A = 1.689 \text{ kWh}$$

Total Actual Energy Used

$$E_{AT} = 10.303 \text{ kWh}$$

$$\text{Efficiency} = \frac{\text{Theoretical Energy}}{\text{Actual Energy}} \times 100$$

$$E = \frac{7.248}{10.303}(100) = 70.3\%$$